Correlation of Process Parameters with Foam Properties in a Foam Fractionation Column Using a Polarized Light Scattering Technique

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Everyday Examples

Cuckoo Spit

Sea foam

Beer head

Cappuccino

Firefighting foam

Dish cleaning foam

Others:

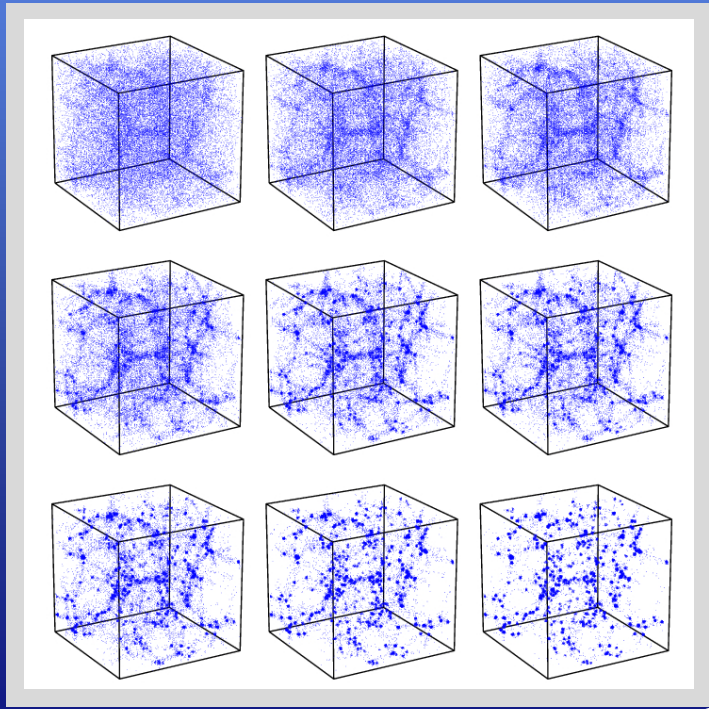
Foods (Ice cream, Meringues, etc)

Cosmetics (Shampoo, Mousse, Shaving cream, Tooth paste, ……)

A Mystery of Fundamental Importance

Each bubble within a foam must take a shape that gives minimal surface area and must also be consistent with the constraining presence of its neighbors.

“Minimal Area Problems”



Technical Importance of Foams

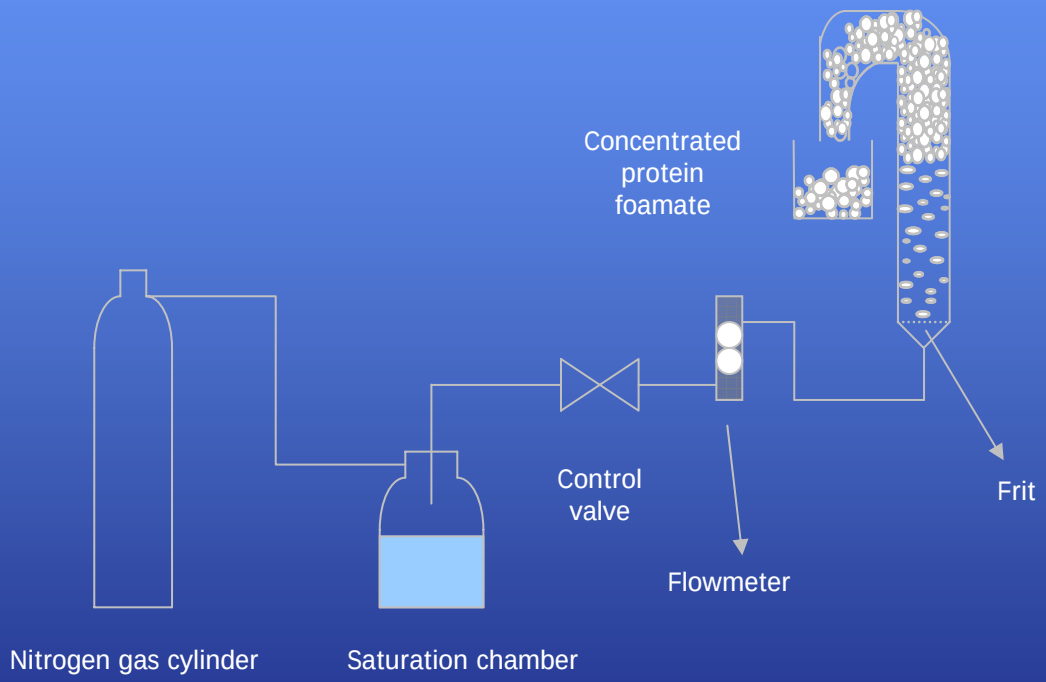
- ✓ Foods, detergents and cosmetics
- ✓ Firefighting
- ✓ Isolation & decontamination of toxic materials
- ✓ Polymer & metallic materials
- ✓ Semiconductor wafer cleaning
- ✓ Oil recovery
- ✓ Physical and chemical separations

Foam fractionation

↓

Enrichment & Recovery of proteins & enzymes

Foam Fractionation



Utility:

- Reduce volumes subjected to chromatography
- Attractive as a downstream processing option to produce value added products from low-value wastes

Advantages:

- Equipment (simple to design, operate and scale-up)
- Inexpensive (low capital & operating cost)
- No thermal energy
- Very small quantity of chemical additives
- Potential for continuous processing

Process Performance

Enrichment

$$E = \frac{C_f}{C_i}$$

Recovery

$$R = \frac{C_f V_f}{C_i V_i}$$

Enrichment → Purpose

Recovery → Economics

Importance of Diagnostics

Consider preparing a cup of cappuccino:

Steam pipe

(Espresso + Milk) → Frothy cappuccino

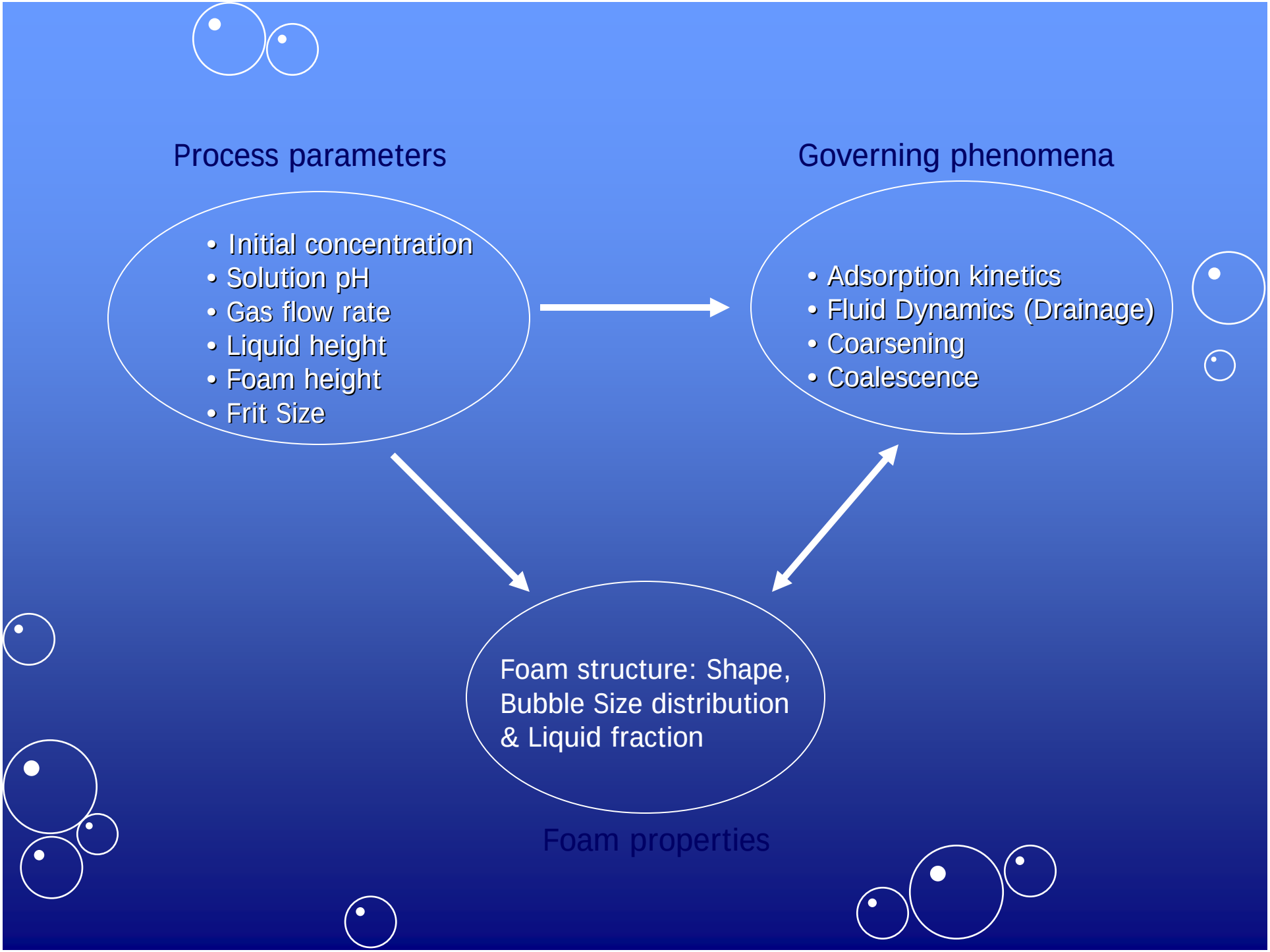
How stiff is the froth??

Small tiny bubbles
densely packed
(Stiff and lasting)

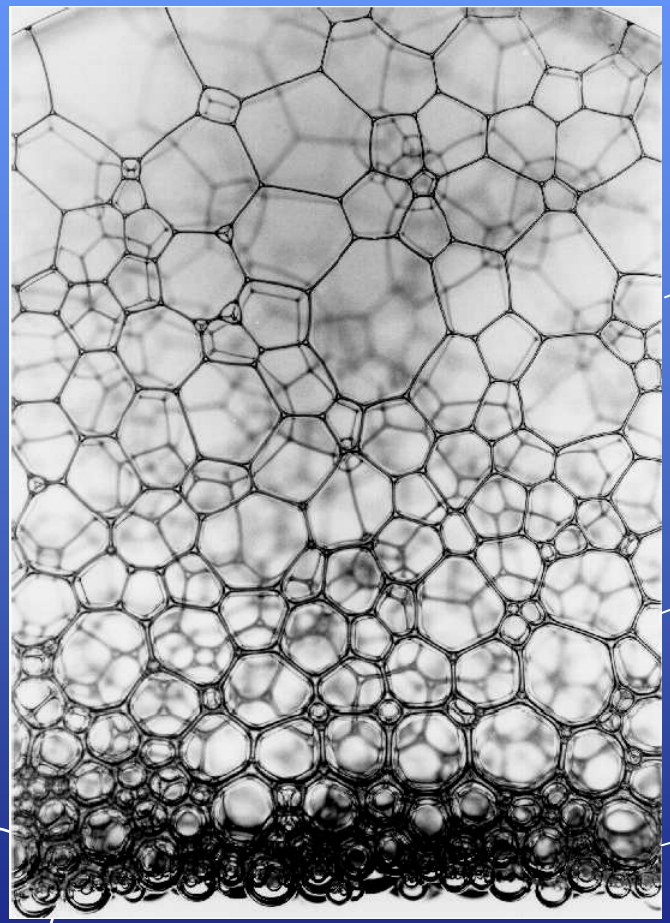
Large bubbles
Non-uniformly packed
(Fragile)

What determines the fate of the froth?

- Quality/type of milk
- Pressure of the steam pipe


Process parameters
• Initial concentration
• Solution pH
• Gas flow rate
• Liquid height
• Foam height
• Frit Size
Governing phenomena
• Adsorption kinetics
• Fluid Dynamics (Drainage)
• Coarsening
• Coalescence
Foam structure: Shape, Bubble Size distribution & Liquid fraction
Foam properties

What Does it Look Like ?

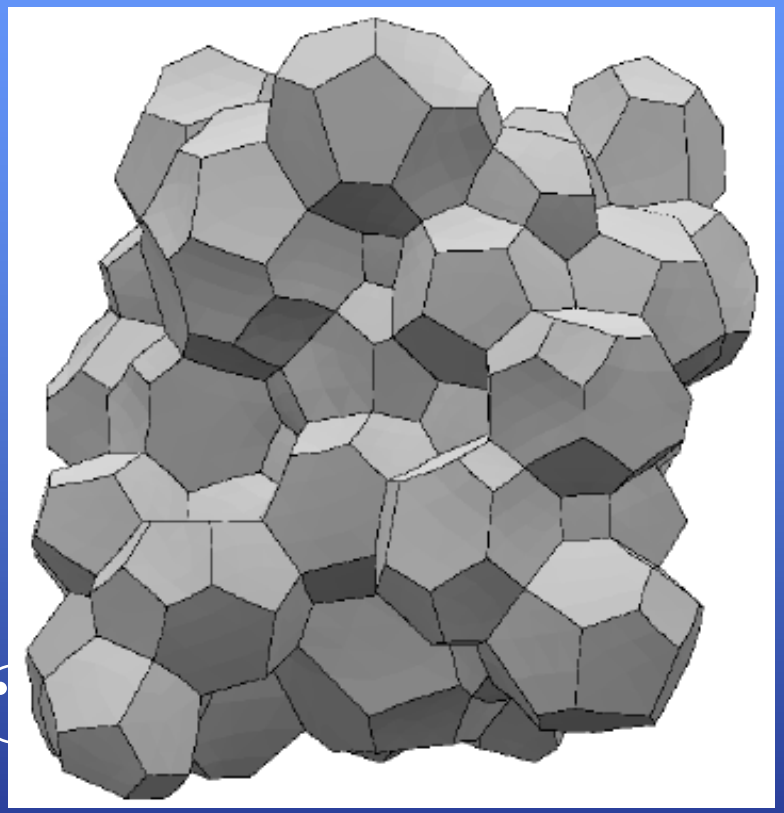


Dry foam with Polyhedral Bubbles

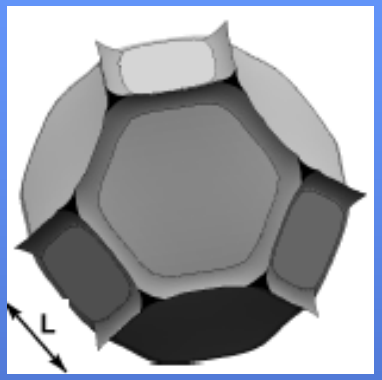
Relatively wetter foam with (distorted spherical/polyhedral) bubbles

Wet foam
(Rigidity loss transition zone)

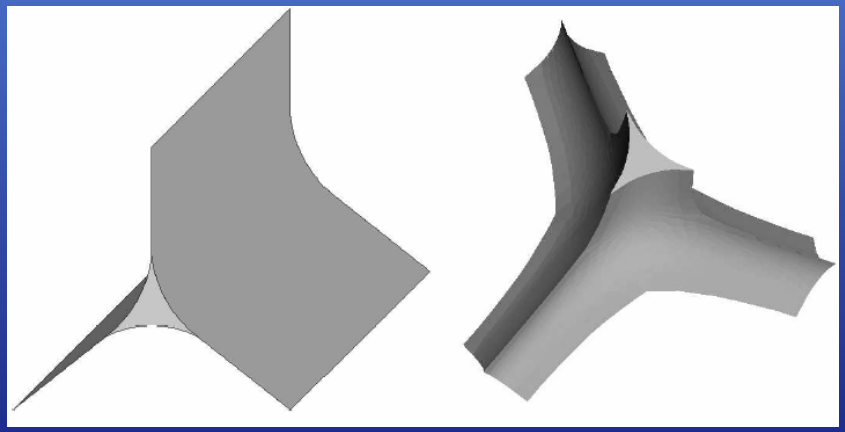
3-D Structure



FOAM



BUBBLE / CELL

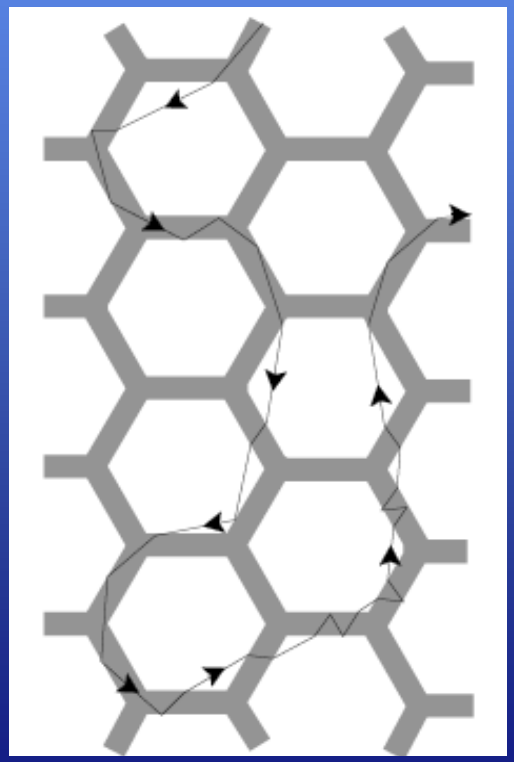


PLATEAU BORDER

Light as a Diagnostic Tool

Individual films are transparent,
Yet, the foam has a white appearance

Multiple scattering behavior



With multiple scattering behavior, cellular structures like foam are expected to change the polarization of light.

Can this attribute be used to measure the properties of foam?

Polarized Light Scattering

STOKES VECTOR:

$$\begin{bmatrix} I & Q & U & V \end{bmatrix}^T$$

$$I = H + V; Q = H - V; U = P - M; V = R - L$$

DEGREE OF POLARIZATION:

$$DP = \frac{\sqrt{Q^2 + U^2 + V^2}}{I}$$

For any scattering medium/event:

$$\begin{bmatrix} I & Q & U & V \end{bmatrix}_{SCA}^T = PM(\Theta) \begin{bmatrix} I & Q & U & V \end{bmatrix}_{INC}^T$$

OBJECTIVE:

Investigate the utility of polarized backscattering measurements to monitor the performance of a foam fractionation process

APPROACH:

In foam fractionation process parameters affect the foam properties which affect the performance

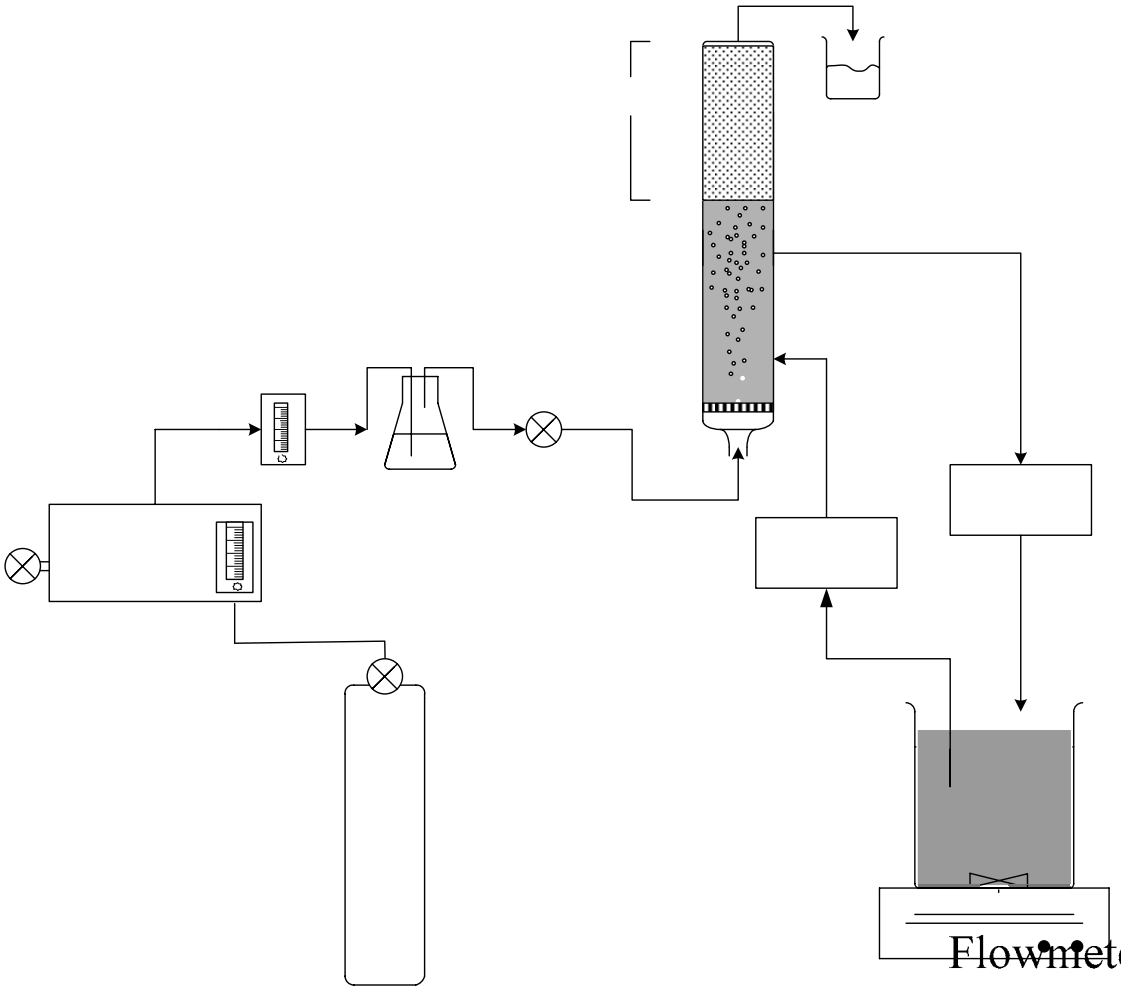
$$R = \frac{C_f V_f}{C_i V_i} \qquad E = \frac{C_f}{C_i}$$

Example:

Low gas flow rate with pH close to neutral → Larger bubbles; drier foam → Higher enrichment; lower recovery

Vary the gas flow rate and pH → Polarized intensity ($I_H = S_{11}+S_{12}$) ↕ Enrichment

FOAM FRACTIONATION



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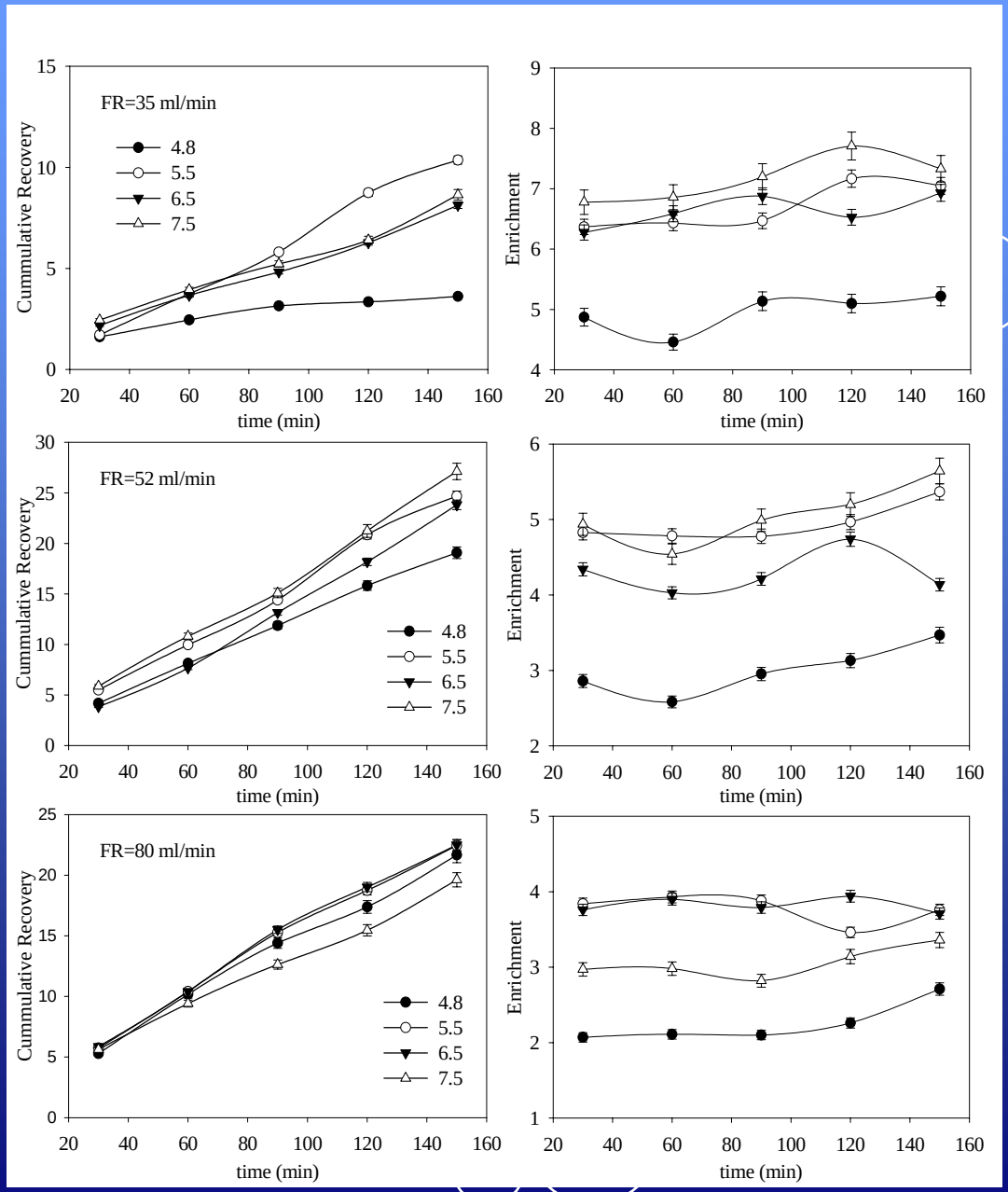
PRELIMINARY EXPERIMENTS

Parameter	Values
Feed solution concentration	0.1 mg/ml
Pool height	35.5 cm ± 0.5 cm
Gas flow rate	35 ml/min, 52 ml/min, 80 ml/min
pH	4.8, 5.5, 6.5, 7.5

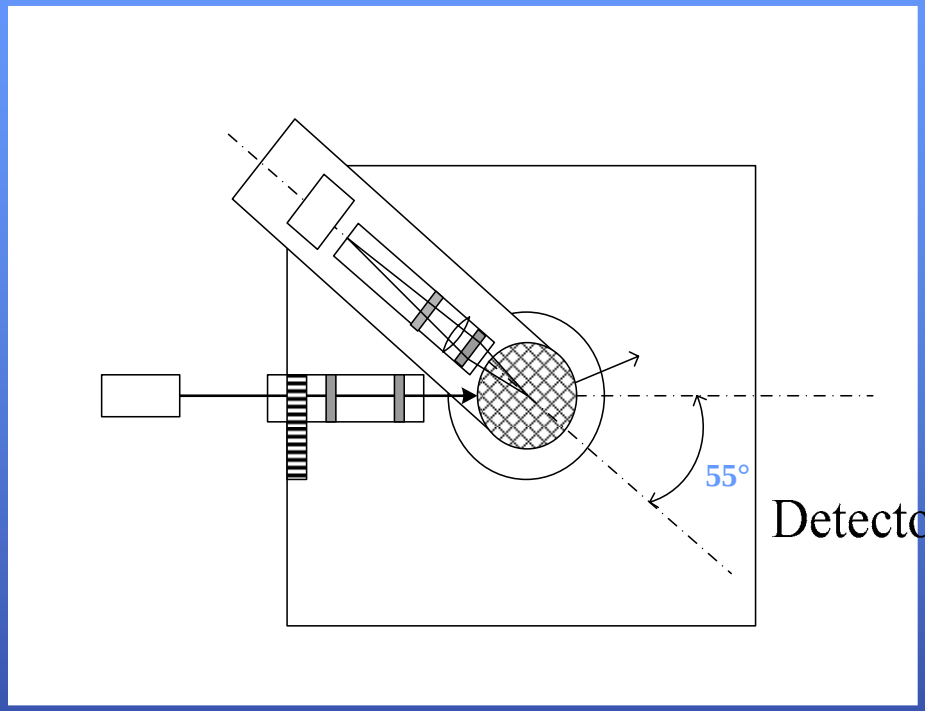
Protein system: BSA

SUMMARY:

- Initial 90 min. provide near constant performance
- pH of 5.5 produces the most consistent enrichment for 90 min. period
- Lower flow rate provides higher enrichment
- pH close to pI(4.8) produces lower enrichment



LIGHT SCATTERING SET UP



P1 is fixed at +45° and P2 is fixed at 0° in order to measure $S_{11}+S_{12}$

Scattering angle is set at 125°

Laser source P1 IRIS-1

65°

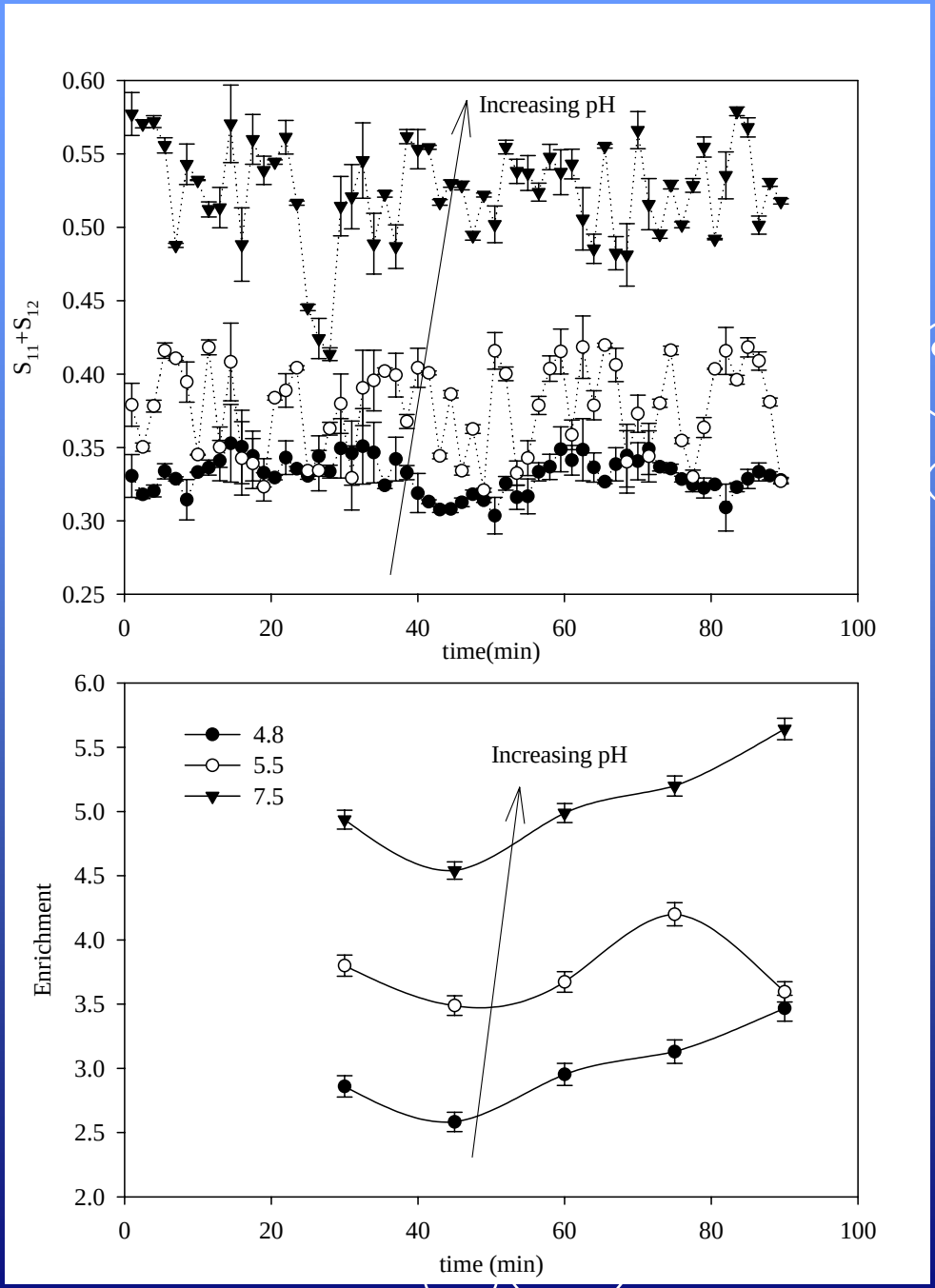
Optical Chopper

EFFECT OF pH VARIATION

Flow rate fixed at 52 ml/min

$S_{11}+S_{12}$ is measured continuously for 90 min.

Enrichment is measured at intervals of 15 min. from t = 30 min

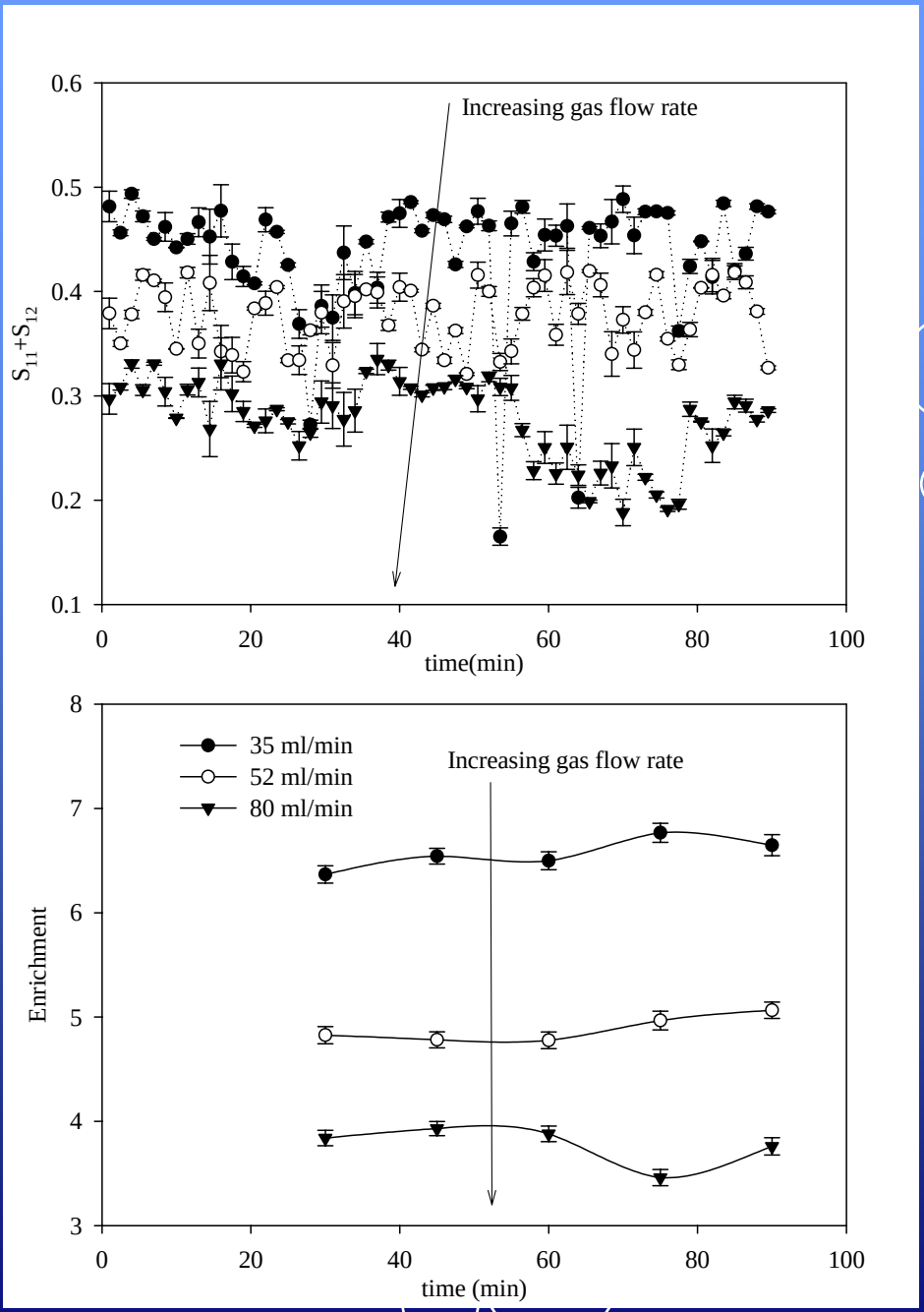


EFFECT OF VARIATION IN FLOW RATE

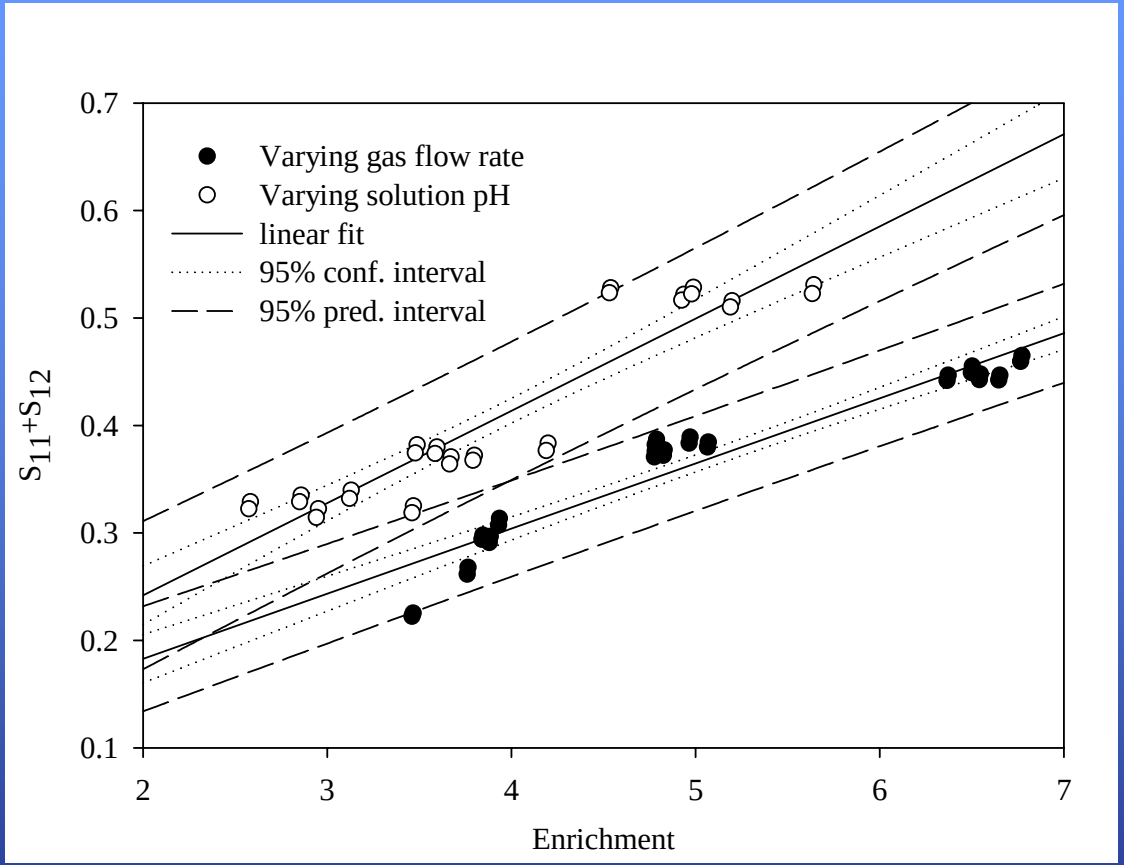
pH fixed at 5.5

$S_{11}+S_{12}$ is measured continuously for 90 min.

Enrichment is measured at intervals of 15 min. from t = 30 min



CORRELATION BETWEEN $S_{11}+S_{12}$ & ENRICHMENT



$R^2 = 0.9186$			
FR	*Coefficients*	*Standard Error*	*P-value*
Intercept	0.0617	0.0177	0.0016
Slope	0.0605	0.0034	8.75E-17

$R^2 = 0.8672$			
pH	*Coefficients*	*Standard Error*	*P-value*
Intercept	0.0704	0.0256	0.0104
Slope	0.0858	0.0063	8.48E-14

ENRICHMENT OBSERVED vs. PREDICTED

$R^2 = 0.9212$

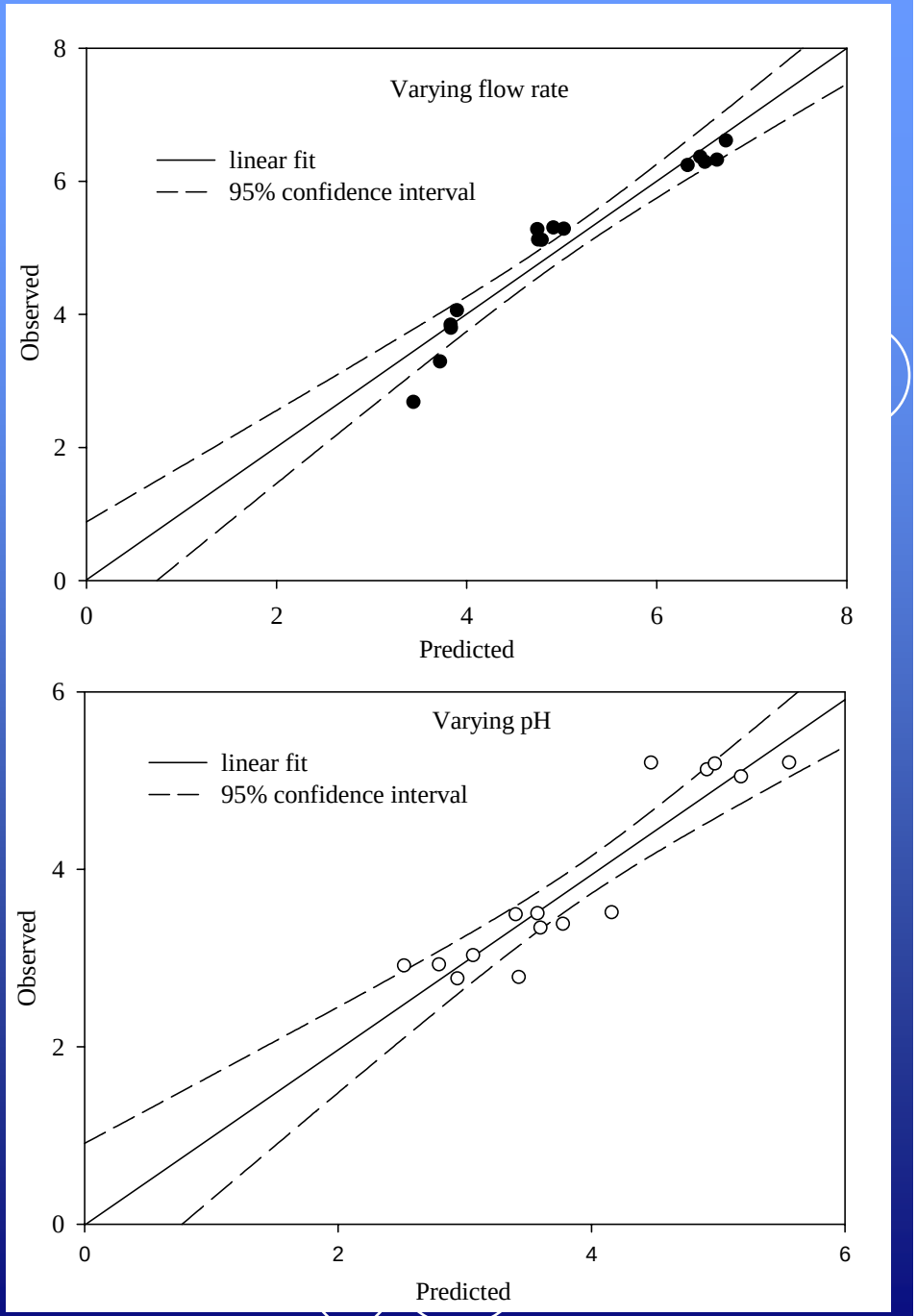
	Coefficients	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.3877	0.335	-0.4500	1.2254
Slope	0.9226	1.51E-08	0.7609	1.0842

Standard error = 0.3479

$R^2 = 0.8593$

	Coefficients	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.5549	0.1741	-0.2788	1.3885
Slope	0.8706	6.72E-07	0.6596	1.0816

Standard error = 0.3658



Questions?